PHYSICAL AND MECHANICAL BEHAVIOURS OF PINEAPPLE LEAF FIBRE REINFORCED THERMOPLASTICS CORN STARCH BIOPOLYMER COMPOSITES

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Who gives me new life, hope and purpose of life

To my beloved father and mother
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ABSTRACT

Recently, the desire to develop environmentally friendly products is growing due to the accumulating of non-biodegradable waste, mainly the disposable product. Starch is one of the potential materials due to the easy availability, low cost, renewability and biodegradability. However, the natural behaviours associated with corn starch (CS) have demonstrated poor mechanical behaviours. Therefore, the modification of CS with the glycerol was applied to form thermoplastics corn starch (TPCS). Hence, characterizations of the TPCS were investigated and the best result was obtained from a mixture of 70 wt.% CS and 30 wt.% glycerol. Meanwhile, pineapple leaf fibre (PALF) is a versatile plant which can be considered a renewable source for composite development. Then, the modification procedure to enhance the behaviours of TPCS reinforced by PALF was employed by using several method; (1) preparation by using multi layers and single layer (2) reinforcement with different lengths of PALF, and (3) treatment with sodium hydroxide (NaOH). PALF reinforcement at the weight ratio of 20:80, 30:70, 40:60, 50:50, and 60:40 was prepared with TPCS. Consequently, the findings showed that the mechanical behaviours of the treated PALF/TPCS bio-composite were improving via single layer. The tensile strength at low PALF loadings produced low values but when reached 40 to 50 wt.%, the tensile strength achieved the highest results. In terms of physical analysis, the preparation of treated PALF/TPCS bio-composite by single layer had a significant impact on moisture absorption and water absorption characteristics. In addition, the tests such as soil burial and water solubility were also affected by the fibre loading. Next, the PALF length affected the physical and mechanical behaviours of PALF/TPCS bio-composite. PALF with a length of 10 mm showed better characteristics than the length of 2 mm and 30 mm. In conclusion, the TPCS/PALF bio-composites are potential materials for biodegradable products such as non-load bearing applications.

ABSTRAK

Kebelakangan ini, keperluan untuk membangunkan produk mesra alam semakin meningkat disebabkan oleh sisa terkumpul yang tidak terbiodegradasi, terutamanya produk pakai buang. Kanji adalah bahan yang berpotensi kerana mudah diperolehi, kos yang rendah, boleh diperbaharui dan mesra alam. Walau bagaimanapun, sifat semulajadi yang berkaitan dengan kanji jagung (CS) adalah mempunyai sifat mekanikal yang lemah. Oleh itu, pengubahsuian terhadap CS dengan gliserol telah dijalankan untuk membentuk kanji jagung termoplastik (TPCS). Oleh itu, pencirian TPCS telah disiasat dan hasil yang terbaik diperoleh daripada campuran 70 wt.% kanji jagung dan 30 wt.% gliserol. Sementara itu, serat daun nanas (PALF) adalah tumbuhan serba boleh yang boleh dianggap sebagai sumber yang boleh diperbaharui untuk di buat komposit. Kemudian, prosedur pengubahsuaian untuk meningkatkan sifat-sifat TPCS yang diperkuat oleh PALF dengan menggunakan beberapa kaedah; (1) penyediaan dengan menggunakan pelbagai lapisan dan lapisan tunggal (2) pengukuhan dengan panjang PALF yang berlainan dan (3) rawatan dengan natrium hidroksida (NaOH). Penguatan PALF pada nisbah berat 20:80, 30:70, 40:60, 50:50, dan 60:40 disediakan bersama dengan TPCS. Hasilnya, penemuan menunjukkan sifat mekanikal bio-komposit PALF/TPCS yang dirawat meningkat melalui lapisan tunggal. Kekuatan tegangan pada beban PALF rendah menghasilkan nilai yang rendah tetapi apabila mencapai 40 hingga 50 wt.%, kekuatan tegangan mencapai hasil yang tertinggi. Dari segi analisis fizikal, penyediaan bio-komposit PALF/TPCS dengan lapisan tunggal mempunyai kesan yang signifikan terhadap sifat penyerapan kelembapan dan penyerapan air. Di samping itu, ujian seperti penanaman di dalam tanah dan kelarutan di dalam air juga dipengaruhi oleh berat serat. Seterusnya, panjang PALF menjejaskan sifat fizikal dan mekanikal bio-komposit PALF/TPCS. PALF dengan panjang 10 mm menunjukkan sifat-sifat yang lebih baik daripada panjang 2 mm dan 30 mm. Sebagai kesimpulan, bio-komposit PALF/TPCS adalah bahan yang berpotensi untuk produk biodegradasi seperti aplikasi tanpa beban.

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LIST OF SYMBOLS AND ABBREVIATIONS

BFRP	-	Biodegradable fibres reinforced polymer
CMC	-	Ceramic matrix composite
CS	-	Corn starch
EoB	-	Elongation on break
FM	-	Flexural modulus
FS	-	Flexural strength
KOH	-	Potassium hydroxide
LDPE	-	Low-density polyethylene
MEKP	-	Methyl-ethyl ketone peroxide
MMC	-	Metal matrix composite
NaOH	-	Sodium hydroxide
PALF	-	Pineapple leaf fibre
PCL	-	Polycaprolactone
PE	-	Polyethylene
PHBV	-	Polyhydroxybutyrate – co hydroxyvalerate
PLA	-	Poly-lactic acid
PMC	-	Polymer matrix composite
PP	-	Polypropylene
PVA	-	Polyvinyl alcohol
PVC	-	Polyvinyl chloride
TBR	-	Tapioca based bioplastic resin
TM	-	Tensile modulus
TPCS	-	Thermoplastics corn starch
TPS	-	Thermoplastic starch
TS	-	Tensile strength

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CHAPTER 1

INTRODUCTION

This section describes the background of the research and the significance of the research that has been performed. This section also represents the problem statement, research objectives, the scope of the study and the significance of the study.

1.1 Background study

Recently, biodegradable fibres reinforced polymer (BFRP), also known as natural fibre composite and it is becoming an interesting research topic for replacing conventional materials, particularly in the packaging industries, construction, furniture and automotive (Bachtiar et al., 2010; Jeffrey et al., 2011). The interest in developing a more environmentally friendly product is growing due to the accumulation of non - biodegradable waste in the landfill. As a result, several "green" materials have been developed to address this issue. The biopolymer derived from renewable resources is a promising alternative material for petroleum-based polymer, as they are biodegradable and therefore environmentally friendly compared to conventional polymers. Varying types of natural resources have been used to produce biopolymers ranging from lipids, proteins, celluloses and starches. Among these sources, starch is considered the most promising with enormous potential resource due to several aspects, such as renewable, low cost and completely biodegradable (Sahari et al., 2013). Starch can be transformed into thermoplastic starch (TPS) under the presence of heat and plasticizer which has similar process ability to traditional thermoplastics. The principal advantages for the production of this material are the thermoplasticity of this biopolymer. It makes manufacturing of this biopolymer using the traditional processing equipment used for synthetic thermoplastics such as extruder and injection molding.

Natural fibres reinforced thermoplastic composites are a relatively new class of BFRP composite materials. This includes natural fibres such as jute, sisal, kenaf, bamboo and pineapple leaf and mixed with synthetic filler such as polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC) and vinyl ester. However, natural fibre has also been used to reinforce with natural filler such as seaweed, clay, talc and eggshell (Bootklad & Kaewtatip, 2013; Coativy et al., 2015; López et al., 2015). Recently, industries in the manufacturing sector are looking for new materials based on natural and renewable sources to be used in their products to reduce the environmental burden. The incorporation of natural material as reinforcement in polymer composites has produced a more environmentally friendly behaviour. Kengkhetkit & Amornsakchai (2014) mentioned that natural fibre composite production is becoming highly attractive and is widely practised due to global warming and oil depletion problems.

In addition, natural fibres in composite materials use less energy during processing, do not pose a health risk when inhaled, do not abrasive the system and reduce the consumption of petroleum resources (Phong et al., 2012; Vinod & Sudev, 2013). According to Selamat et al., (2014) natural fibres play an important role in the development of biodegradable composites to address the current environmental and ecological problems. Moreover, these green solutions would reduce the dependence of the manufacturing industry on synthetic materials such as glass fibres, which are often associated with a high risk potential for employees. Developing more environmentally friendly materials offers the manufacturing industry a new option for replacing the synthetic polymer in their production.

1.2 Problem statements

Nowadays, the high demand and consumption by the manufacturing industry of petroleum-based polymer produced serious environmental problems, particularly during the disposal phase. This disposal of waste is not readily biodegradable at the landfill or shore, because these waste contain dangerous chemicals which may damage the environment, biodiversity and human health (Maran et al., 2014). Moreover, the use of petroleum-based polymer also will cause air pollution that contributes to global warming and oil resource depletion. Therefore, in recent years, many countries have restricted the use of plastic bags as a way of tackling this problem (López, Castillo, et al., 2015). Hence, this research aimed to resolve this problem by producing a 100% renewable and biodegradable polymer composite from sustainable materials.

Corn (also known as maize) is one of the world's primary starch sources. Corn starch derived from corn grain can be turned into a thermoplastic material which has a stiff property with heat and plasticizer. However, neat thermoplastic starch has drawbacks that hinder its use in commercial plastics industries such as poor mechanical strength and high susceptibility to water (Babaee et al., 2015). This restriction has limited the potential use of this resource in actual life. Therefore, adequate modifications should be applied to improve the characteristics of this material, such as reinforcing it with high potential natural fibres.

Natural fibres are more environmentally friendly than synthetic fibres, which are comparatively more expensive and have non - biodegradable attributes. In other terms, natural fibres have many unique properties, including such low cost, low density, environmentally friendly, biodegradable, specific strength properties and face minimum potential health risks (Pickering et al., 2016). The pineapple leaf fibre is one of the natural fibres that inspired researchers to explore its potential in composites as a strengthening material. (Todkar & Patil, 2019). PALF has several advantages as it grows rapidly and requires only several months to grow. Thus, after harvesting season, it is easy to recover and the pineapple leaf fibre is relatively stable compared to other natural fibres like cotton, kenaf and jute (Jawaid & Abdul Khalil, 2011). Furthermore, the pineapple leaf fibre is a traditional bio-resourced material that has not been wholly used and is also an abundant natural source in Johor, especially in pineapple plantations.

In addition, the combination of natural fibres such as pineapple leaf fibre with the petroleum-based polymer matrix would yield only partial biodegradable material. Hence, it is necessary to use pineapple leaf fibre as a reinforcement in polymer composites that use TPS as a matrix to create a fully biodegradable material. Therefore, the intention of this research are (1) to determine the best behaviours of thermoplastics corn starch (2) to tackle the incompatibility issue of pineapple leaf fibre reinforced composite (3) to widen the potential application of pineapple leaf fibre and finally (4) the most important outcome is to create a completely biodegradable substance that can be disposed of securely in the environment.

1.3 Objectives

This research aims to develop and classify natural resource dependent biodegradable and renewable materials. Four principal goals of this research are:

1. To investigate the effect of different fibre types of untreated pineapple leaf fibre reinforced thermoplastic corn starch composites physical and mechanical behaviour at varying fibre loading.
2. To evaluate the behaviour of different fibre lengths of untreated pineapple leaf fibre reinforced thermoplastic corn starch composites physical and mechanical behaviour at varying fibre loading.
3. To compare the effect of treated and untreated pineapple leaf fibre reinforced thermoplastic corn starch composites physical and mechanical behaviour at varying fibre loading.
4. To evaluate the behaviour of different fibre lengths of treated pineapple leaf fibre reinforced thermoplastic corn starch composites physical and mechanical behaviour at varying fibre loading.

1.4 Scope of the study

This study attempts to get a deeper understanding of the characteristics of pineapple leaf fibre (PALF) reinforced thermoplastic corn starch (TPCS) in terms of, physical and mechanical behaviours due to the different fibres types, the different fibre lengths and the effect of treated PALF at varying fibre loading. The approach of this investigation is based on experimental studies. The study is categorized into three distinct phases.

The first phase of this study is the characterisation of maize starch. Corn starch used in this study was taken from the manufacturing type and in powder form. TPCS was produced using glycerol as a plasticizer. TPCS was compressed with four parameters to determine the appropriate compression moulding parameters, i.e. temperature, pressure, preheat period and compression length. The selected temperature was between 150°C and 200°C, the pressure was between 10 kg/cm^2 and 30kg/cm^2, preheat duration was about 5 minutes to 20 minutes and compress duration was about 5 minutes to 20 minutes. TPCS was packed using seven different loadings of glycerol, which are 20%, 25%, 30%, 35%, 40%, 45% and 50%. Mechanical, physical and morphological characterizations were conducted.

The second phase of this study is to determine the effect of different types of fibres on the physical and mechanical behaviours of the PALF reinforced TPCS composite. Two different fibre types are the single layer (random orientation) and multi layers (laminates) were chosen for this study. Besides that's, two different fibre lengths, which are 2 mm and 10 mm were chosen to use in this phase. The results of these two different fibre types and two different lengths of PALF was measured, and the sample behaviour were experimentally observed. The best fibre types and length of PALF that gave the highest value of physical and mechanical behaviours were chosen for the next stage of this study.

The third phase emphasizes the influence of alkaline treatment on PALF. Treatment effects on the physical and mechanical behaviours of PALF reinforced TPCS as a polymer matrix were studied. In this analysis, Sodium Hydroxide (NaOH) was employed as the chemical to treat the PALF. In addition, two different fibre lengths, which are 10 mm and 30 mm were chosen to use in this phase. The results of untreated and treated PALF/TPCS bio-composites in two different lengths were compared.

The PALF used in this study was from Josapine cultivar and the PALF was bought from Pontian, Johor. PALF reinforced TPCS was fabricated with five different fibre loadings, which are 20%, 30%, 40%, 50% and 60%. The preparation of PALF/TPCS bio-composites samples was prepared using the compression moulding technique with random orientation of the PALF. The bio-composite specimens have been examined for their physical and mechanical behaviours. Tensile, flexural and impact experiments were carried out to determine the mechanical behaviour of PALF/TPCS bio-composites. Density, moisture content, moisture absorption, water absorption, soil burial and water solubility testing were conducted to analyse the physical behaviour of PALF/TPCS bio-composites. SEM analysis was carried out to analyse the PALF/TPCS bio-composites fracture behaviour.

1.5 Significance of the study

1. The results of the present study are expected to enhance the awareness of the development of a biodegradable polymer matrix from corn starch.
2. In this study, the production of the biodegradable polymer matrix with enhanced behaviour is expected to help address the environmental question of alternative materials for the petroleum-based polymer.
3. The issue of petroleum-based polymers, such as environmental pollution during production and disposal, can be mitigated by the use of entirely biodegradable and renewable polymer composites produced from TPCS and PALF.
4. In the area of waste management, this research explored the potential new application of PALF from Josapine cultivar reinforced TPCS for development bio-polymer composites.

CHAPTER 2

LITERATURE REVIEW

This section aims to explain the literature from this study further. This section comprises the previous research work on biodegradable fibres reinforce polymer (BFRP) composites, polymer matrix, thermoplastics starch, corn starch, natural fibre and pineapple leaf fibre (PALF). Findings from previous research and the objectives of this study are also discussed in this chapter.

2.1 Introduction

Previously, humans were aware of the function of composite materials. The records of composites which dated back to historical applications are utilized in construction applications. For instance, in countries like Africa and India, straw or husks like Figure 2.1 (a) were used with mud or clay to construct houses as shown in Figure 2.1 (b) and (c) and this been done for several hundred years (Khalafalla, Mohamad and Mayyuta, 2013). Straw or husks used in the process will provide the strength and structure while mud or clay will function as a binder and tie the straw together (Akinkurolere et al., 2006; Singh, Kumar, & Waghmare, 2016).

(a) (b) (c)

Figure 2.1: Building using straw and mud (Khalafalla, Mohamad & Mayyuta, 2013)

2.2 Composites

Generally, a composite material may be described as a combination of two or more materials in order to provide unique combined properties. As a whole, the integral materials will work together but still remain in their original forms and this will create the final properties of composite materials which are better than the fundamental material properties (Mazumdar, 2002). Elanchezhian et al. (2018) in their study stated that the composite is a combination of two materials in which one of them, defined as the reinforcing phase, is deposited in the form of fibres, sheets or crystals, and the other materials known as the matrix phase.

The reinforcing phase is the delivery step in the structure, through which other reinforcing products such as natural fibre, synthetic fibre, particle etc. were made available during that period (Santosh Kumar et al., 2015). Bunsell & Renard (2005) stated that fibres which are used as reinforcement could be divided into three groups which are regenerated, synthetic and natural. The natural fibres can be divided into three subgroups which are animal, vegetable and lastly mineral fibres as shown in Figure 2.2. According to Mazumdar (2002), the main functions of the fibres are (a) to carry the load in which the fibres carry 70 to 90% of the load, (b) to provide strength, stiffness, thermal stability and other structural properties and last but not least (c) to provide insulation or electrical conductivity depending on the type of fibre.

The matrix phase is also known as the composites continuous step and can be a polymer-metal or ceramic (Santosh Kumar et al., 2015). Based on this three basic metrics, the composite can be categorized into three common composite types: Polymer matrix composite (PMC), Metal matrix composite (MMC) and Ceramic matrix composite (CMC) composite as shown in Figure 2.3. However, the selection of matrix is based on the application, properties required and also method of the manufacturing processes (Kumar, Mohan, & Mahesha, 2015; Lau et al., 2018). Based on Mazumdar (2002), the matrix material fulfils several functions in a composite structure and the importance of a matrix material include the following: (a) binds the fibres together and transfers the load to the fibres.as as it also provides the shape and rigidity to the structure (b) isolates the fibres so that individual fibre can act separately. This will stop or slow down the crack propagation and (c) provides a better surface finishing quality and aids in the production of net-shape or near-net-shape parts as well

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